

## Chapter 15

# PROJECTING TECHNOLOGICAL CHANGE

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**Abstract.** Improving efficiency in the use of both wood and nonwood inputs has characterized the US forest sector over the last 50 years. This chapter explores methods used to reflect this pattern of technological change and others in the Timber Assessment Projection System models. The development and use of three types of technology projection methods are explained: (1) decomposition of technology into several processes and projection of future mixes of processes to make exogenous projections of technology change for harvesting costs and for solidwood products recovery and processing costs in TAMM; (2) activity analysis that uses alternate technologies capable of changing fiber input mixes to make endogenous projections of technology change for pulp, paper, and paperboard production in NAPAP; and (3) innovation diffusion modeling to endogenously project the change in wood-use rates in major end uses such as housing in TAMM. We provide an example of a sensitivity testing in a case where technology projections were made exogenously. Finally we discuss lessons learned and points to consider when deciding the type of technology projection methods to use.

**Keywords:** technological change, efficiency, forest product processing

## 15.1 INTRODUCTION

As indicated in Chapter 9, the “base case” projections from the Timber Assessment Projection System (hereafter Assessment System) are generally intended to represent a continuation of past trends in macroeconomic variables, with no change in existing forest policies, but the base case does simulate shifts in certain market conditions such as shifts in regional production capacities for forest products. When projecting

technological change, it would be more accurate to say that we project, to the extent possible, change based on continuing forces that influence technology change for particular types of wood and paper products and for end uses that use wood products. Continuing forces include competition to develop processes and products that have lower costs or better performance. One example would be the continued measures to reduce costs of lumber production generally and improve efficiency of converting logs to lumber specifically. We make projections for a number of conversion processes by using a mix of methods that use more than just extrapolation of past trends. In particular, we identify specific alternate technologies and project their adoption in response to competition and changing economic conditions.

From the earliest post-World War II Timber Assessments, the triple goals of better utilization of harvested timber, improved processing technology, and the adoption of new products with enhanced performance properties have been seen as ways to increase the ability of timber supplies to meet demand for products and end uses. In the process of developing the Timber Assessments, meeting these three goals is the impetus for developing projections of technological change. This chapter describes the assumptions and the methods used to project technological capabilities for harvesting, product manufacturing, and wood use in various end uses. As a general caveat, the specific kinds and degrees of technological change need to be updated periodically to reflect the most recent outlook for likely technological capabilities.

### **15.1.1      Techniques for projecting technological change**

In general, there are at least three techniques and associated rationales to use in preparing projections of technological capabilities (Bright 1978, p. 26): (1) extrapolate trends—that is, assume a steady pace of technology change over time, (2) project change based on emerging innovations, their capabilities, and exogenously estimated pace of adoption, and (3) project change based on anticipated response to needs and economic conditions.

Prior to the 1980s, before the use of modern Assessment System models, Forest Service projections of technical change were based entirely on the first method—trend extrapolation. The second method is an improved form of trend extrapolation, which decomposes production into several discrete technologies and exogenously projects their adoption. This technique is used to exogenously project change

in harvesting costs, and processing costs and conversion efficiencies for softwood lumber, softwood plywood, and OSB. These exogenous projections are used in the TAMM model. We use the third method when (1) we use the NAPAP model to endogenously shift production among alternate paper and paperboard production processes in response to cost of raw materials and nonmaterial costs or (2) we use the TAMM model to shift wood-use intensity in end uses in response to changes in price competition with steel and concrete. Our projection methods rely on the principle that decomposition can help improve projections that involve judgment (Armstrong 1978). Decomposition is defined as identifying particular innovations, and judging (or modeling)—for each innovation—its efficiency of material use, cost of production, and pace of adoption.

Technological capabilities change over time for each stage of wood product production and use. The stages of production for which technical change in the Assessment System are modeled include: (1) sawtimber harvesting, (2) primary wood products processing—lumber, structural panels, and paper, and (3) wood product use in solid-wood product end uses. Technological change in timber growth (production) and its impact on timber supply is described separately in Chapters 6 and 12 as projected changes in the number of acres of timberland by forest types and management intensity class.

As indicated in Table 15-1, the technological capabilities we project include (1) processing costs, (2) conversion efficiencies, including wood raw material use and paper recycling rates, (3) rates of wood product use (wood use factors) in end uses (e.g. residential housing), and (4) use of new sources of wood supply, specifically agricultural SRWC. We project processing costs and conversion efficiencies for harvesting, for softwood lumber and plywood, and for OSB, exogenously for TAMM. We project production costs and conversion efficiencies endogenously within the NAPAP model for various grades of pulp, paper, and paperboard (including paper recycling rates), and we project endogenously in NAPAP the capacity to use agricultural SRWC. Wood product use rates are projected for lumber and panel use in housing, alteration and repair, nonresidential construction, manufacturing, and shipping.

Certain technological capabilities are projected exogenously by using either constant values or a continuation of trends including: (1) hardwood lumber processing costs and conversion efficiency, (2) nonstructural panel conversion efficiency, and (3) wood product use factors for end uses other than housing.

Table 15-1. Methods used to project technology change for the base case

Conversion or use process	Technology capability that is projected		
	Processing cost per unit of wood product output	Wood product output per unit of wood input	Wood-use per unit of end use
Logs into softwood lumber	Exogenous adoption of discrete innovations	Exogenous adoption of discrete innovations	
Logs into softwood plywood	Exogenous adoption of discrete innovations	Exogenous adoption of discrete innovations	
Logs into OSB	Exogenous trend estimate	Exogenous trend estimate	
Logs into hardwood lumber	Fixed over time	Fixed for each size of log input	
Logs and residue into nonstructural panels		Fixed over time	
Logs, residue, recycled paper, and short rotation woody crops into market pulp, paper, and paperboard	Endogenous adoption of discrete process innovations	Endogenous adoption of discrete process innovations	
Use of softwood lumber and structural panels in housing			Endogenous adoption based on competition with steel and concrete
Use of softwood and hardwood lumber, and structural panel use in (1) housing alteration and repair, (2) nonresidential construction, (3) manufacturing, and (4) shipping			Extrapolation

Certain technological capabilities are projected endogenously by having a model shift production and production capacity among competing processes. This method is used to project (1) pulp, paper, and paperboard processing costs and associated wood conversion efficiency,

and recycling rates in the NAPAP model, and (2) lumber and panel use rates in housing and other key end uses in the TAMM model. This endogenous modeling involves costs/revenue comparisons of alternate production technologies in the case of pulp, paper, and paperboard, and cost comparisons for wood and other materials in end uses such as housing. The projections are influenced by the endogenously determined prices of inputs (e.g. wood or recovered paper), and thus these technological changes are driven by projected market conditions.

Certain technological capabilities are projected exogenously by using side calculations that shift production among processes. This method is used to project (1) harvesting costs, and (2) softwood lumber and plywood processing costs and conversion efficiency.

Some technological projections reflect changes due to the rate of diffusion of new products (and not just new processes). This was true for the 1958 and 1965 Outlook Studies, which included speculation about the adoption of softwood plywood and nonstructural panels that by the 1980s influenced various conversion factors. The best example of explicit modeling of the diffusion of innovations, in the form of new products, is Spelter's model for the diffusion of innovations in use of softwood lumber, softwood plywood, and OSB (Spelter 1985; also see Sect. 15.7 and Chap. 3). The discussions in this chapter on both the adoption of different processes to make a single product and the adoption of one product to replace another (e.g. wood products end use in housing), follow Rogers' (2003) general model of the diffusion of innovations.

## **15.2 TECHNOLOGICAL CHANGE IN SAWTIMBER HARVESTING**

Harvest of sawtimber trees includes tree felling, bucking the tree into logs, skidding or yarding the logs to a landing, and loading them for hauling to a processing facility. To project harvesting and transport cost per unit (e.g. cubic meters, thousand board feet) of sawtimber in each US region, the production costs were estimated for a range of current harvesting systems in each region. These systems are shown in Table 15-2. Each system was developed to be close to the "optimum" for the typical diameter/volume/terrain in each region (Bradley 1989).

Harvesting costs are influenced by the mix of harvesting systems used (a technical change) and by operating conditions such as average

Table 15-2. Projected proportion of timber harvested by system and region, 2000–2040 (Haynes 1990, p. 203)

Region and terrain	Estimated proportion of harvest				
	2000	2010	2020	2030	2040
South-flat:					
Roundwood					
Cable skidders	30	25	20	15	10
Grapple skidders	47	51	55	59	63
Bobtail trucks	16	15	14	13	12
and farm tractors					
Whole tree chippers	7	9	11	13	15
North—flat:					
Roundwood					
Cable skidders	51	40	31	22	14
Grapple skidders	29	33	36	39	41
Forwarders	9	13	17	20	24
Whole tree chippers	11	14	16	19	21
North and South-steep:					
Roundwood					
Cable yarders	16	22	28	34	40
Skidders and forwarders	84	78	72	66	60
Rocky Mountains:					
Tractors—jammers	84	82	80	77	75
Cable yarders	16	18	20	23	25
Pacific Southwest:					
Highlead	6	6	6	5	5
Skyline—short	25	25	25	26	27
—medium	8	9	10	11	12
—long	0	0	1	1	1
Tractors	61	60	58	57	55
Pacific Northwest West:					
Highlead	18	16	14	12	10
Skyline—short	38	38	39	39	40
—medium	8	9	9	10	10
—long	3	3	3	3	3
Tractors	33	34	35	36	37
Pacific Northwest East:					
Highlead	3	4	4	5	5
Skyline—short	13	13	14	14	15
—medium	6	7	7	8	8
—long	0	1	1	2	2
Tractors	78	75	74	71	70

tree diameter and volume harvested per hectare. A model was developed to estimate harvesting costs for each system as average diameter of sawtimber trees and average volume harvested is changed (Bradley 1989). Average diameter of trees and average volume per hectare harvested were projected over time by using preliminary projections from ATLAS. Average diameter of sawtimber harvested was projected to increase slightly in the North, decrease slightly in the South, and decrease in the West. Average volume harvested per hectare was projected to increase in the North, South, and Rocky Mountains, and remain constant in the rest of the West. Estimated harvesting and hauling cost were also influenced by projected increases in real labor and energy costs.

Projections of average sawtimber harvesting cost over all systems used in a region were obtained by using a weighted average of costs of individual systems, where costs were weighted using projections of the proportion of volume harvested under each system. Expert judgment was used to estimate the proportion of volume harvested using each system over time. The projected proportions are shown in Table 15-2.

Log and haul costs (in deflated dollars) were projected to increase at a faster rate over the next 50 years than over the last 50 years. Increases are due primarily to projected declines in diameter of sawtimber to be harvested, and to a lesser degree, to increasing labor and energy costs. Projected increases from 2000 to 2050 range from about 30% in the West to 40% in the South and North (Figure 15-1). In general, the regional ranking from highest to lowest harvest and haul cost per unit volume is as follows: North, Pacific Southwest, Rocky Mountains, Pacific Northwest West, Pacific Northwest East, and South.

### **15.3 TECHNOLOGICAL CHANGE IN PRODUCING SOFTWOOD LUMBER**

Softwood lumber processing includes yard handling of logs, debarking, bucking, log breakdown by primary and secondary sawing, planning, drying, grading, and preparation for shipping. To project softwood lumber recovery (lumber output per unit of log input) and softwood lumber processing costs per unit of lumber in each US region, the conversion efficiency and processing costs were estimated for a range of current and likely future processing systems. Systems were specified for four levels of technology for each of three types of sawmills (stud,

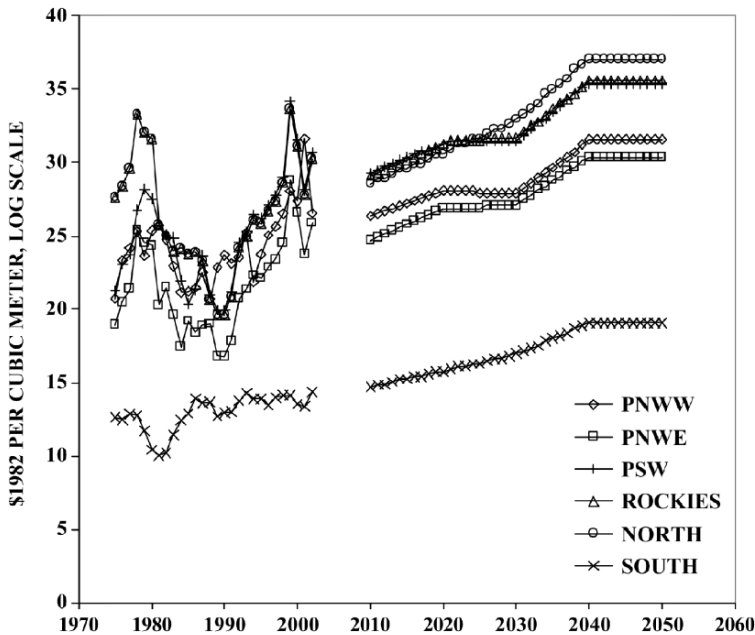


Figure 15-1. Sawtimber harvest and haul costs, 1975–1995, with projections to 2050. PNWW = Pacific Northwest West, PNWE = Pacific Northwest East, PSW = Pacific Southwest.

random length dimension, and board). The levels of technology are (1) old average producing less than 8,300 m<sup>3</sup> per year,<sup>1</sup> (2) old average producing more than 8,300 m<sup>3</sup> per year, (3) traditional, and (4) new. These systems are described in Haynes (1990, Table 133) and Skog (1989). The future sawmill designs include many specific innovations that were envisioned as likely (Haynes 1990, pp. 205–206).

For each sawmill design and region, lumber recovery was estimated (for each projection year) by using a recovery equation. Recovery was estimated as a function of projected average log diameter, and values for headsaw and resaw kerf,<sup>2</sup> dressing allowance, and the percentage of theoretical yield that is achievable. Parameter values for various technologies are shown in Haynes (1990, Tables 133 and 135). The recovery equations were developed by using software that computes log breakdown by the Best-Opening-Face method (Lewis 1985).

<sup>1</sup> Five million board feet per year.

<sup>2</sup> Kerf—the width of a cut made by a saw blade.

For each sawmill design and each region, average processing cost per unit of lumber output over time was estimated by preparing a complete set of estimates of capital and operating costs over time, taking into account expected changes in log volume throughput as log diameter changes (Williston 1987, Skog 1989). Costs exclude log cost and revenue from sale of mill residue.

Projections of average softwood lumber recovery and processing costs over all systems used in a region were made by using a weighted average of conversion efficiencies and processing costs of individual systems, where amounts were weighted by using the projected proportions of lumber produced by each system. Proportions were projected based on input of plywood manufacturing specialists at FPL and an industry consultant. The projected proportions are shown in Table 15-3. These projected lumber recovery factors (LRF) and processing costs were used as exogenous assumptions in TAMM.

The average softwood LRF in the USA in 2000 was about 0.46 cubic feet of lumber (solid contents) per cubic meter of sawlog input<sup>3</sup> or 46% recovery. Average US conversion efficiency was projected by using the method discussed above to increase about 17% to 54% recovery by 2050. Average sawlog diameters are projected to increase slightly in the South, and in the West. Lumber recovery starts at a high level in the Pacific Northwest West and increases modestly. Improvements are slightly more rapid in the South and other western regions (Figure 15-2).

Softwood lumber nonwood processing costs (in real dollars) are projected to decline in all regions (Figure 15-3). This decline is due to improvements in technology—less capital, labor and energy per unit of lumber throughput, and assumed stable real labor and energy costs. Declines between 2000 and 2050 range from –21% in the Pacific Northwest (West and East), to –13% in South and Pacific Southwest and –16% in the Rocky Mountain regions.

## **15.4 TECHNOLOGICAL CHANGE IN PRODUCING SOFTWOOD PLYWOOD**

Two types of softwood plywood are produced: sheathing and sanded. Sanded products require relatively clear face veneers whereas sheathing may have faces with knots. Sheathing plywood and interior plys for sanded plywood can use lower quality veneer from lower quality

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<sup>3</sup> 6.8 board feet of lumber per cubic foot of log input.

Table 15-3. Projected proportion of softwood lumber mills by system and region, 2000–2040

Region and terrain	Estimated proportion of harvest				
	2000	2010	2020	2030	2040
North:					
Old less than 8,300 m <sup>3</sup> per year	54	49	43	38	33
Old more than 8,300 m <sup>3</sup> per year	3	0	0	0	0
Traditional	41	39	31	20	7
New	2	12	26	42	61
South:					
Old less than 8,300 m <sup>3</sup> per year	19	17	15	13	11
Old more than 8,300 m <sup>3</sup> per year	6	0	0	0	0
Traditional	73	64	46	28	9
New	3	20	39	59	80
Rocky Mountains:					
Old less than 8,300 m <sup>3</sup> per year	11	10	9	7	6
Old more than 8,300 m <sup>3</sup> per year	7	0	0	0	0
Traditional	80	69	50	30	9
New	3	21	42	63	84
Pacific Southwest:					
Old less than 8,300 m <sup>3</sup> per year	0	0	0	0	0
Old more than 8,300 m <sup>3</sup> per year	8	0	0	0	0
Traditional	89	77	54	32	10
New	3	23	46	68	90
Pacific Northwest:					
Old less than 8,300 m <sup>3</sup> per year	1	1	1	1	0
Old more than 8,300 m <sup>3</sup> per year	8	0	0	0	0
Traditional	88	76	54	32	10
New	3	23	45	67	90

smaller diameter logs. Over the projection period, the diameters of softwood veneer logs are projected to decline in all regions. The extent to which smaller trees may be used and retain good veneer recovery and lower costs depends on the ability of technology to deal with the following characteristics of smaller logs: (1) a higher proportion of wet sapwood, which decreases dryer capacity; (2) an increase in the tapered part of the log versus the cylindrical part, which decreases veneer yield per log; (3) the rise in the fraction of wood in the log which is left as an unpeeled core; and (4) the increase in wood loss due to error in centering the log in the lathe, which decreases recovery.

To project softwood plywood recovery (plywood output per unit of log input) and softwood plywood processing costs, the conversion

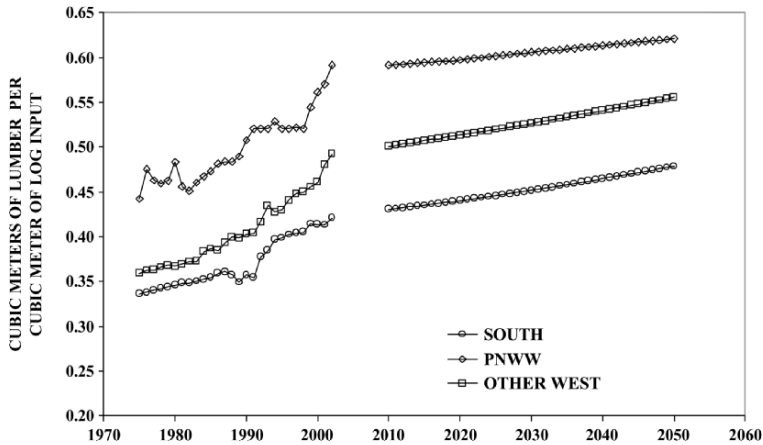


Figure 15-2. Softwood lumber recovery, cubic meters of lumber per cubic meter of logs, log scale, 1977–1995, with projections to 2050.

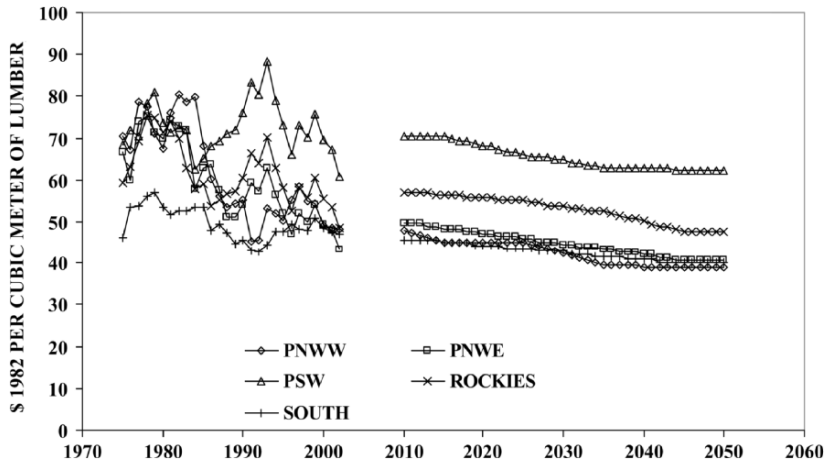


Figure 15-3. Softwood lumber nonwood processing costs, \$1982 per cubic meter of lumber, 1975–1995, with projections to 2050.

efficiency and costs were estimated for a range of processing systems in each US region. Systems were specified for three levels of technology in each region: (1) old, (2) traditional, and (3) current. These systems are described in Haynes (1990, pp. 214–216).

For each plywood mill design in each region, plywood recovery was estimated (for each projection year) by using a recovery equation. Recovery was estimated for technology as a function of projected

log diameter and values for percentage of bolts that spinout, spinout core size, target core size, ratio of actual to nominal veneer thickness, and clipper speed using the PLYMAP computer program developed by Spelter (1990). The PLYMAP program was also used to estimate processing costs per unit output for each technology in each region over the projection period.

Projections of average softwood plywood recovery and processing costs over all systems used in a region were made by weighting them by the projected proportion of plywood produced by each system. Proportions were projected based on input of plywood manufacturing specialists at FPL. The projected proportions are shown in Table 15-4. These projected plywood recovery factors and processing costs were used as exogenous assumptions in TAMM.

The average softwood plywood recovery factor (PRF) in the USA in 2000 was about 0.64m<sup>3</sup> plywood per m<sup>3</sup> of veneer log input or 64% recovery. Average conversion efficiency was projected to increase about 2% to 66% by 2050. Average veneer log diameters are projected to decrease in the West and remain relatively stable in the South (Haynes 1990, Table 140). PRF, on a percentage basis, is projected to increase most in the South, where veneer log diameter is projected to remain relatively stable (Figure 15-4.). Because we only projected adoption of “current” technologies, and mills with these technologies have a life of up to several decades, the change in PRF

Table 15-4. Projected proportion of softwood plywood mills by system and region, 2000–2040

Region and terrain	Estimated proportion of harvest				
	2000	2010	2020	2030	2040
South:					
Old	5	0	0	0	0
Traditional	70	65	63	62	60
Current	25	35	37	38	40
Pacific Northwest West:					
Old	30	20	17	16	15
Traditional	55	52	51	50	50
Current	15	28	32	34	35
Pacific Northwest East:					
Old	20	15	12	10	10
Traditional	68	65	60	55	55
Current	12	20	28	35	35

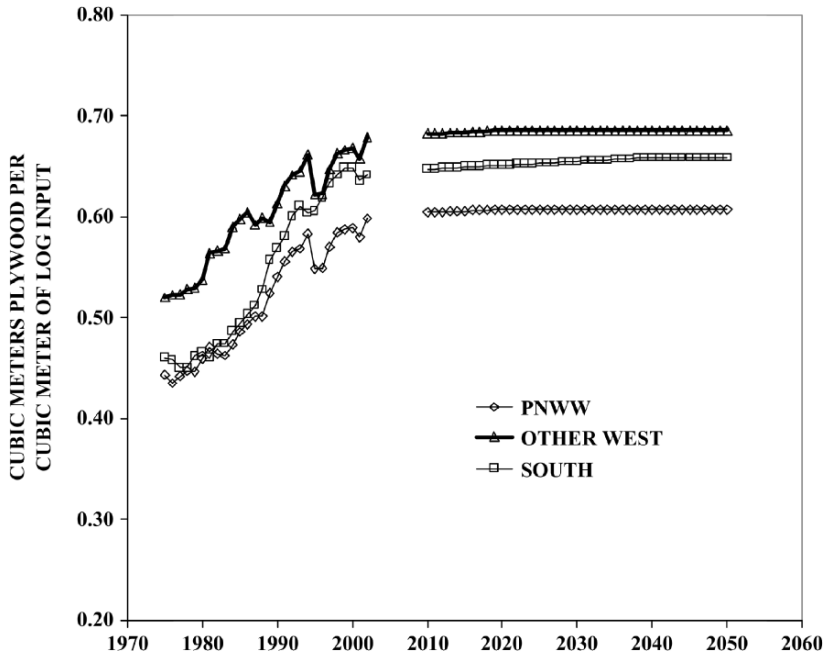


Figure 15-4. Softwood plywood recovery, cubic meters plywood per cubic meter of log input, 1975–1995, with projections to 2050.

is projected to be small after 2010 or so. Softwood plywood technology is considered to be relatively mature and future improvements in recovery are considered limited.

Softwood plywood nonwood processing costs (in real dollars) are projected to decrease slightly over the projection period even though log diameters decrease primarily due to labor and energy savings improvements in technology (Figure 15-5).

## 15.5 TECHNOLOGICAL CHANGE IN PRODUCING OSB

OSB has been used as sheathing for walls and roofs, for subflooring, and for concrete forms and siding. Unlike conventional particleboards, the raw material normally comes direct from roundwood rather than mill residue. Projections of wood-use efficiency and nonwood processing costs were made by evaluating current technology and making judgments about what factors could change and by how much.

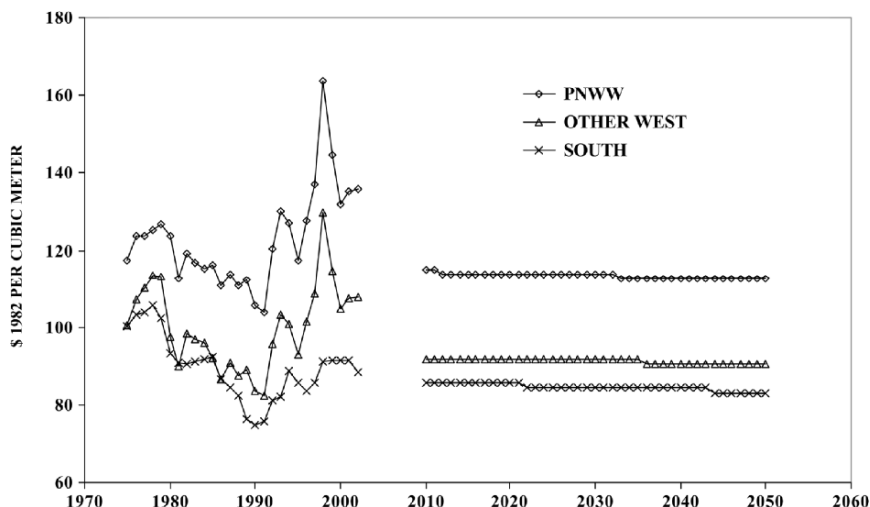


Figure 15-5. Softwood plywood nonwood processing costs, \$1982 per cubic meter of softwood plywood, 1975–1995, with projections to 2050.

Wood-use efficiency improvements can be made by reducing wood loss during flaking, forming, and trimming. Wood recovery in making OSB is estimated to be between 55% and 60% based on a loss of 4% for trimming logs and log rejects; 8–12% loss as fine wood material, 35% loss for panel densification and 3% for panel trim. We did not envision separate, newer technologies that would improve recovery and costs as for softwood lumber and plywood. Instead we judged that current losses could be reduced by 2 % over the projection period from the trims and fines loss of 15–19%. OSB manufacturing costs can be reduced by reducing the amount and cost of adhesives. It was judged that other types of cost reductions would be limited, and overall the nonwood manufacturing costs would decline by 4% over the projection period based on adhesive savings.

## 15.6 TECHNOLOGICAL CHANGE IN MAKING PULP, PAPER, AND PAPERBOARD

The NAPAP model projects production, consumption, and trade for all pulp and paper products, including nine grades of paper, four grades of paperboard, and five grades of market pulp. It uses activity analysis to allocate production among competing processes, an

economic optimization approach pioneered by Takayama and Judge (1964). The activity analysis approach was extended to include capacity constraints by production process and shifts in production capacity using the Tobin's  $q$  theory of capital investment behavior (see Chap. 4). The NAPAP model projects, endogenously, changing capacities among all competing processes used to make pulp, paper, and paperboard products in the USA and Canada (see Tables 4-8 through 4-12).

The competing processes represent all principal categories of mill technologies that are actually employed in the North American pulp and paper industry. For example, four processes are employed at newsprint mills, including (1) mills with groundwood pulping capacity, (2) mills with thermomechanical pulping capacity (3) mills using deinked 100% recycled pulp, and (4) mills with chemithermomechanical pulp capacity. Most grades of paper and paperboard have more than one type of production process (like newsprint). Two grades of paper and paperboard, and all grades of market pulp have just a single production process. For each process, the fiber input requirements and other real costs of production remain fixed over the projection period, but average inputs and costs for the industry and for certain products change as the production capacities of competing processes are projected to change over time.

For each production process, the mix of fiber inputs is limited by a specified range of feasible fiber input combinations, which can include hardwood and softwood pulpwood, market pulp or recovered paper. Thus, the shares of market pulp, recycled fiber, and pulpwood used in paper and paperboard products change in relation to changing fiber markets and changing capacities of production processes. For each of the paper or paperboard production processes, paper or paperboard may be produced by using up to six different mixes of softwood pulpwood, hardwood pulpwood, wood pulp and recovered paper inputs. For each of the wood pulp production processes, pulp may be produced by using up to two different mixes of softwood and hardwood pulpwood. The NAPAP model determines the optimal allocation of fiber inputs each year among all competing processes.

As discussed in detail in Chapter 4, the expansion of capacity for a certain process in each successive projection year is a function of the Tobin  $q$  ratio for that process in the current and preceding year, and the change in capacity of the preceding year. The  $q$  ratio is computed as the ratio of the shadow price for a unit of capacity to the cost of a new unit of capacity (see equation 4.10).

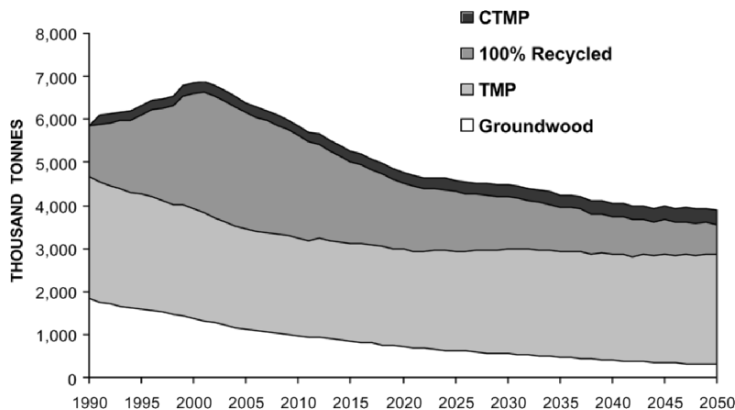


Figure 15-6. Estimated cumulative US production of newsprint by processing technology, 1990–2005 and projections 2010–2050. CTMP = chemithermomechanical, TMP = thermomechanical.

All of the processes in the current version of the NAPAP model represent currently available technologies that are actually employed in the industry, although some are newer or more advanced than others. Some of the processes have been growing in capacity, while others have been declining in capacity, and the NAPAP model has accurately tracked capacity changes by process since 1986.

An example of the projected capacities is shown for processes used to produce newsprint in Figure 15-6. For each process, the mix of fiber inputs—softwood and hardwood pulpwood, market pulp and recovered paper—will vary within a feasible range of inputs in response to changing input prices. The average cost per tonne (metric ton) of newsprint and the average inputs per unit output change over time as the capacities of processes change and the mix of inputs change.

As noted previously, the production processes represented in the current version of the NAPAP model do not include any future alternative processes, but hypothetical future processes can be included in the model. A future process is defined in the model by specifying its fiber input requirements, nonfiber costs, the cost of capacity expansion, and the product produced. The model will then project the competitive evolution of the future process as well as existing production processes. Such future processes were incorporated into earlier versions of the NAPAP model, and results described in supporting documents (Ince 1994).

## **15.7 TECHNOLOGY CHANGE IN USE OF SOLID-WOOD PRODUCTS IN MAJOR END USES**

In the Assessment System, technological change in major end uses for solid-wood products is modeled as shifts in the mix of two broad classes of available technologies: (1) production methods that use wood in an intensive way and (2) methods that use wood in a less intensive way, or that use nonwood materials. Key end uses modeled in this fashion in TAMM include single family houses, multifamily houses, nonresidential buildings, shipping, and railroad ties. In the case of single family houses, wood-use intensity is modeled separately for basements, wall and roof framing, floor framing, roof sheathing/siding, and millwork/flooring. The rate of use, called the use factor, was projected over time for softwood lumber, softwood plywood, and OSB. The use factor is the quantity of wood product used per unit of end use output (e.g. cubic meters of softwood lumber per square meter of floor area of single family houses).

For each product and end use, a wood intensive technology was defined by an estimate of the maximum amount of wood that could be used per unit of end use output (e.g. cubic meters of softwood lumber for roof sheathing or siding per square meter of floor area). Also, for each product and end use, a technology was defined that used less wood, including cases where different amounts of wood products were used or nonwood material was used. For example, in the case of roof sheathing and siding, wood panels could be used instead of lumber. The annual change in wood-use factor in each end use was projected from a starting use rate based on the difference between the projected cost of using the wood-intensive method versus those of the low-wood-intensity or nonwood method. The cost to use wood in each end use is determined endogenously based in part on the price of each wood product, determined in the Assessment System, while the cost to use nonwood materials is projected exogenously. This diffusion model approach was developed by Spelter (1985) and is described further in Chapter 3.

As an example, Figure 15-7 shows historical and projected use factors for softwood lumber consumed in single family houses, multifamily houses, and mobile homes. The use factor for single family housing is a composite of the factors for basements, wall and roof framing, floor framing, roof sheathing and siding, and millwork and flooring.

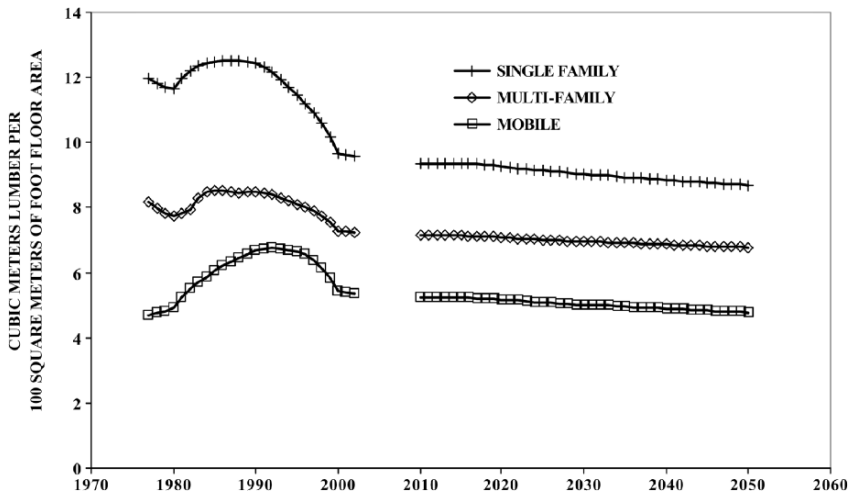


Figure 15-7. Softwood lumber use factor in housing in board feet per 100 m<sup>2</sup> of floor area, 1980–1995, with projections to 2050.

The projected decline in the softwood lumber use factor in single family housing is due to the higher cost of wood-intensive production methods compared to less intensive wood-using technologies such as use of wood trusses in roofs and floors.

## 15.8 IMPACTS OF ACCELERATED SOFTWOOD LUMBER RECOVERY IMPROVEMENTS

Alternative views of future trends in wood- and fiber-use technologies can be examined in the Assessment System by modifying the exogenous trends in costs and recoveries for logging and the solid wood products, and by adding or altering technologies and input mix options in the pulp, paper, and paperboard sector. To illustrate the possibilities, we examine the effects of increasing the projected improvements in softwood lumber recovery factors. This is a potentially significant issue because softwood lumber accounts for 61% of all current (2003) softwood roundwood consumption in the USA. Its share of consumption falls to 49% by 2050 in the base projection, although its absolute use rises slightly. How sensitive are the levels of US softwood lumber consumption, regional production and US–Canadian trade patterns to improved technology? What impacts do

altered wood input requirements have on regional softwood harvests and private inventories?

We explore this sensitivity to technology change by making two alternate projections, where softwood lumber recovery improves more quickly than the base case projections: (1) raising recovery improvements to half the annual rates observed in each region historically between 1975 and 2005 (except for Eastern Canada, where recovery is allowed to rise at its historical rate), and (2) raising improvements to the full historical rate (except Eastern Canada, which rises at 1.5 times the historical rate).<sup>4</sup> These trends are illustrated in Figure 15-8. Key results are summarized in Table 15-5 for the softwood lumber market and the stumpage sector. In both cases total softwood lumber supplies to the US market expand, lumber prices fall, and consumption rises. Because the rates of productivity improvement are exponential, the impacts of applying the full historical improvement rate are much more than twice those of the half historical rate case. US production expands in both cases but is partially displaced by even more rapid

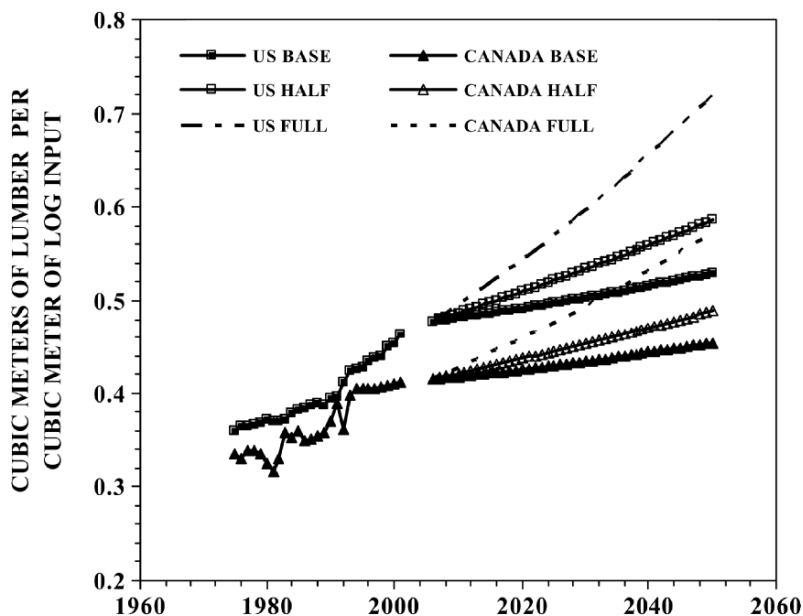


Figure 15-8. Average US and Canadian softwood lumber recoveries for base and scenarios: half historical rate of improvement and full historical rate.

<sup>4</sup> Eastern Canada is treated differently because its base case productivity improvement is somewhat faster than the historical trend.

Table 15-5. Impacts of more rapid rates of improvement in softwood lumber recovery in the US and Canadian industries, percent changes from base levels, “half” of historical average improvement rate (1975–2005) and “full” historical rate

Year	US softwood lumber production		US softwood lumber consumption		US softwood lumber imports		US softwood lumber producer price index	
	Half	Full	Half	Full	Half	Full	Half	Full
<i>Percent change from base</i>								
2010	0.42	0.65	0.06	0.19	−0.41	−0.40	−0.42	−1.59
2020	0.72	0.84	0.33	1.06	−0.26	1.33	−1.66	−6.48
2030	0.98	0.73	0.52	1.76	−0.20	3.20	−2.95	−9.68
2040	1.50	0.99	0.76	2.51	−0.40	4.66	−3.71	−12.62
2050	1.64	1.15	0.80	3.16	−0.51	6.06	−3.76	−14.57
South softwood sawtimber price		Pacific Northwest West softwood sawtimber price		US softwood sawtimber harvest		US private softwood growing stock		
	Half	Full	Half	Full	Half	Full	Half	Full
2010	−0.48	−0.06	−4.47	−8.77	−0.49	−1.45	0.01	−0.08
2020	−1.24	−2.24	−6.89	−15.55	−2.24	−6.90	0.29	0.62
2030	−2.39	−6.31	−13.29	−27.89	−3.83	−11.69	0.98	2.80
2040	−3.11	−9.47	−19.45	−40.86	−5.30	−15.96	2.09	5.88
2050	−3.82	−11.78	−25.50	−51.45	−6.31	−20.02	3.58	9.85

expansion in Canadian output and rising imports in the full rate case. In all cases US softwood sawtimber harvest falls together with regional softwood sawtimber stumpage prices. This leads to larger private softwood timber inventories in the long term.

15.9 CONCLUSIONS

Rather than projecting change in the processing costs or conversion efficiency based on a continuation of past trends, we have used decomposition methods and activity analysis methods. These methods identify likely technological changes and apply judgment (or models) to indicate how the continued force of competition will drive adoption (growth) of the new technologies and thereby change processing costs and conversion efficiency. The presumed benefit of using these decomposition methods for solid-wood products is to reduce the error in

projections when compared to an extrapolation of previous trends (Armstrong 1978). For example, the 1973 Outlook Study efforts projected improved lumber conversion efficiency at 2% per decade. The methods in Section 15.3 project a higher rate of improvement in lumber conversion efficiency: 2–5% per decade, depending on the region. The variation among regions is influenced both by improvements in scanning, control, and breakdown technology, and by the projected size of logs that are processed.

The activity analysis approach used in the NAPAP model identifies the production processes used in industry, defines those processes by their costs and input requirements, and then determines the optimal allocation of production activities among existing processes. That general approach was pioneered by Takayama and Judge (1964). The approach was extended to include shifts in capacity based on the Tobin  $q$  model. The activity analysis provided a more accurate rationale for modeling, and accuracy in projecting, significant structural change, such as expansion of paper recycling since the 1980s.

Endogenous projections of the mix of production technologies over time has the advantage over exogenous projections because the projected mix of technologies changes in response to the changing cost advantage for each technology in accordance with economic theory. Exogenous projections are useful because they can be used in an existing modeling structure to improve simple trend extrapolation estimates. Models that use exogenous projections could use alternate technology projection scenarios to cover a range of uncertainty concerning technological change as indicted by the example evaluation of the impact of alternate rates for lumber recovery improvement in Section 15.8. The decision to use endogenous versus exogenous projections in a model can be made by considering the benefit of endogenous projections relative to additional effort required (or other modeling features left out) and comparing that net benefit to the benefits and costs of a simpler model that evaluates technological change by using several alternate exogenous technological change scenarios.

By using the decomposition method to project technological change for solid-wood products, we have learned how to translate the knowledge of engineers and innovators about specific expected innovations into projections of technological change for solid-wood production processes. For example, we developed an engineering model, for soft-wood sawmills that indicates how efficiency and costs will change with saw kerf, dressing allowance, and log diameter. By using the sawmill

engineering model, we were able to quantify the significant impact of changing log diameter on efficiency and costs. The use of the engineering models to estimate costs also clarified the role of future energy costs in estimating costs of production, although we did not take full advantage of this knowledge to explore the impact of alternate projections of energy prices.

By using the activity analysis method to project technology change for paper and paperboard products, we have learned two things. First, the method produced accurate projections of the changing mix of technologies over a historical period, particularly the increase and leveling of production using recovered paper. Second, the method produced accurate projections of changing mix of technology that were relatively insensitive to modest differences in production costs estimates. This may be because the model allows for both substitution among wood inputs to technologies (hardwood, softwood, recovered paper) as well as allowing for shifts from one technology to another.

## REFERENCES

- Armstrong JS (1978) Long-range forecasting from crystal ball to computer. Wiley, New York
- Bradley DP (1989) When you say harvest and transport cost you've said it all (or nearly all)! In: Proceedings of timber supply: perspectives and analysis. Series Rep 64. University of Minnesota, College of Natural Resources and Agricultural Experiment Station, Department of Forest Resources Staff, pp. 145-162. <http://fr.cfans.umn.edu/publications/staffpapers/Staffpaper64.pdf>
- Bright JR (1978) Practical technological forecasting. Industrial management Center, Inc, Austin, TX
- Haynes RW (coord) (1990) An analysis of the timber situation in the United States: 1989-2040. Gen Tech Rep RM-199. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO
- Ince PJ (1994) Recycling and long-range timber outlook: background research report 1993 RPA assessment update. Res Pap FPL-RP-534. USDA Forest Service, Forest Products Laboratory, Madison, WI
- Lewis DW (1985) Sawmill simulation and the best opening face system: a user's guide. Gen Tech Rep FPL-48. USDA Forest Service, Forest Products Laboratory, Madison, WI. <http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr48.pdf>
- Rogers EM (2003) Diffusion of Innovations. Free Press, New York
- Skog KE (1989) Forecasting technological change in softwood lumber processing. In: Proceedings of 23d annual Pacific Northwest regional economic conference, Corvallis, Oregon, 1989 April 26-28, Northwest Policy Center, Seattle, WA, pp55-62. <http://fpl.fs.fed.us/documnts/pdf1989/skog89a.pdf>

- Spelter H (1985) A product diffusion approach to modeling softwood lumber demand. *Forest Sci* 31(3):685–700
- Spelter H (1990) PLYMAP—A computer simulation model of the rotary peeled softwood plywood manufacturing process. Gen Tech Rep FPL-GTR-65. USDA Forest Service, Forest Products Laboratory, Madison, WI. <http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr65.pdf>
- Takayama T, Judge GG (1964) An interregional activity analysis model of the agriculture sector. *J Farm Econ* 46(2):349–365
- Williston E (1987) Engineering estimates for softwood sawmill technology forecasting. Report under contract FPL-87-13 to the USDA Forest Service, Forest Products Laboratory, Madison, WI